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Park**

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(54) **SEMICONDUCTOR DEVICE HAVING
VERTICAL CHANNEL, RESISTIVE MEMORY
DEVICE INCLUDING THE SAME, AND
METHOD OF MANUFACTURING THE SAME**

USPC 438/585; 257/2, 365, E29.264, E21.545
See application file for complete search history.

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Notice of Allowance issued by the USPTO for a continuation-in-part U.S. Appl. No. 14/460,204 of the parent U.S. Appl. No. 14/074,404 on Oct. 29, 2015.

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(57) **ABSTRACT**

A semiconductor device, a resistive memory device including the same, and a method of manufacturing the same are provided. The semiconductor device includes a pillar extending substantially perpendicular from a semiconductor substrate, the pillar including an inner portion and an outer portion surrounding the inner portion. A junction region is formed in an upper region and a lower region of the vertical pillar, and a gate surrounds the pillar. The inner portion of the pillar includes a semiconductor layer having a lattice constant that is larger than a lattice constant of the outer portion of the pillar.

5 Claims, 8 Drawing Sheets

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(51) **Int. Cl.**

H01L 21/336 (2006.01)

H01L 29/66 (2006.01)

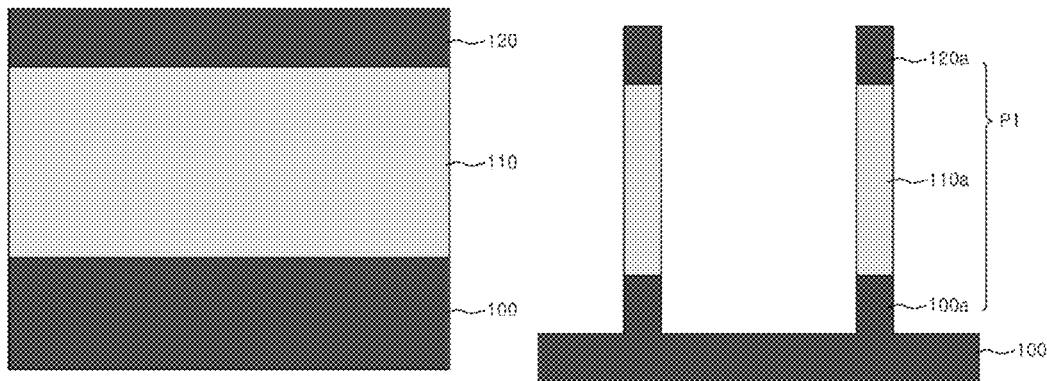
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(58) **Field of Classification Search**

CPC H01L 21/762; H01L 29/78



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FIG.1



FIG.2

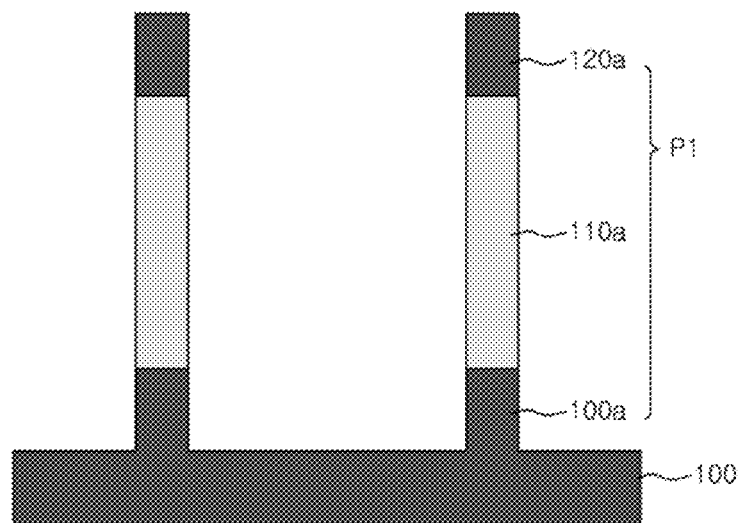


FIG.3

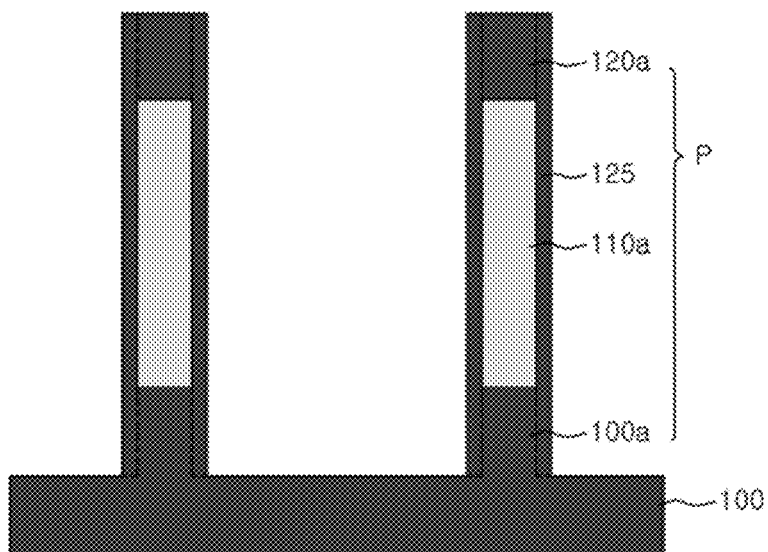


FIG.4

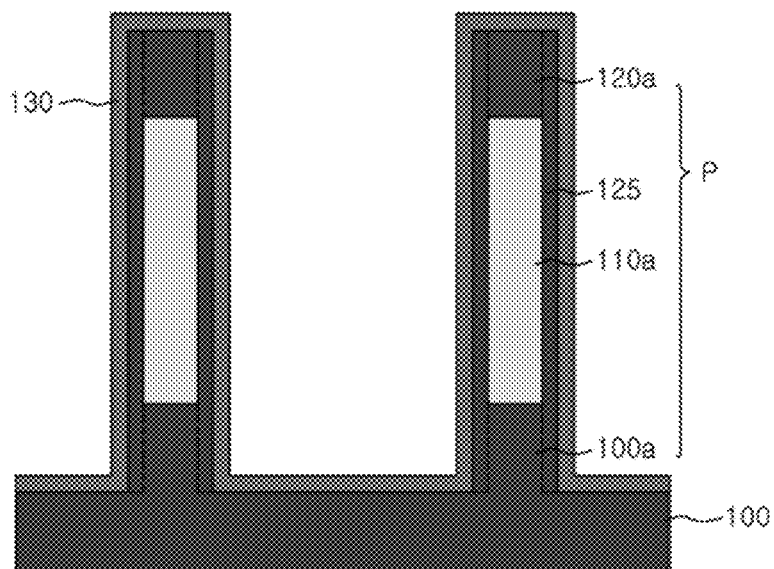


FIG.5

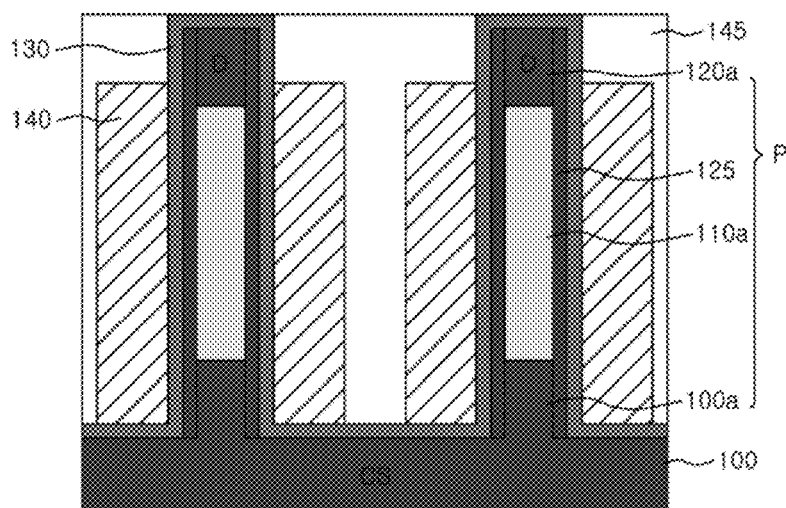


FIG.6

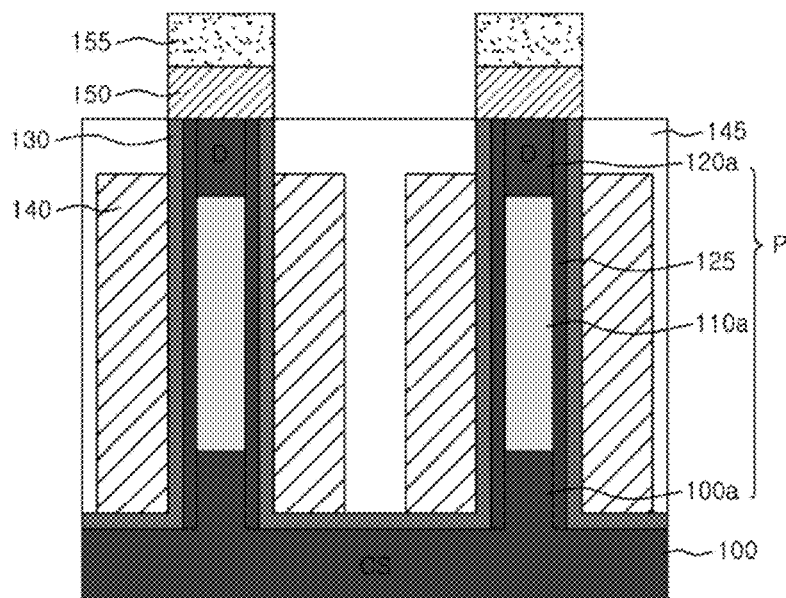


FIG. 7

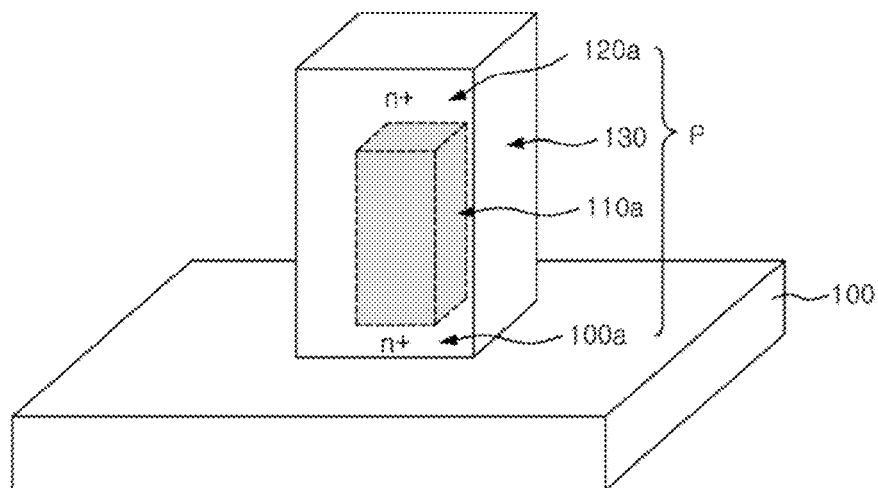


FIG. 8

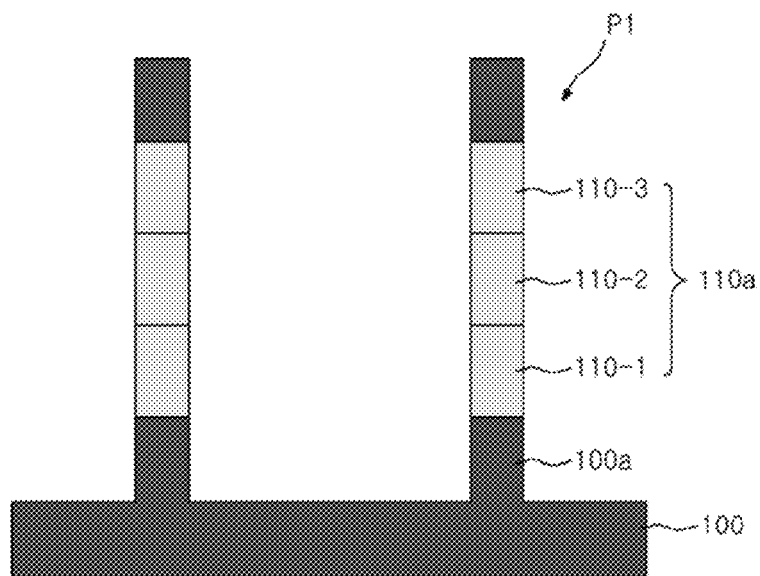


FIG. 9

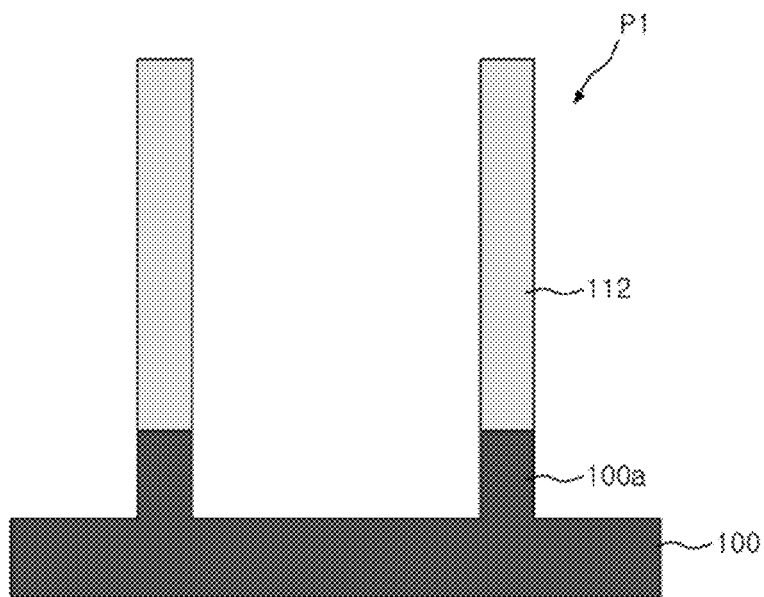


FIG. 10

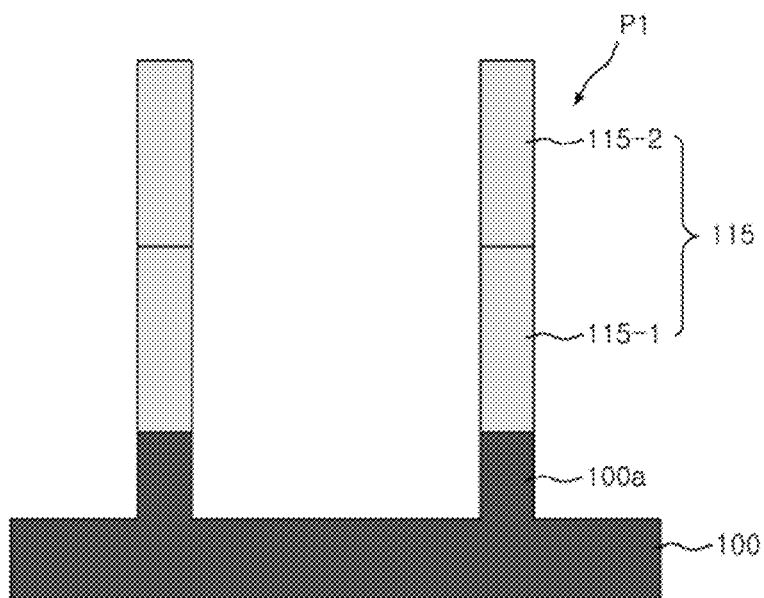


FIG. 11

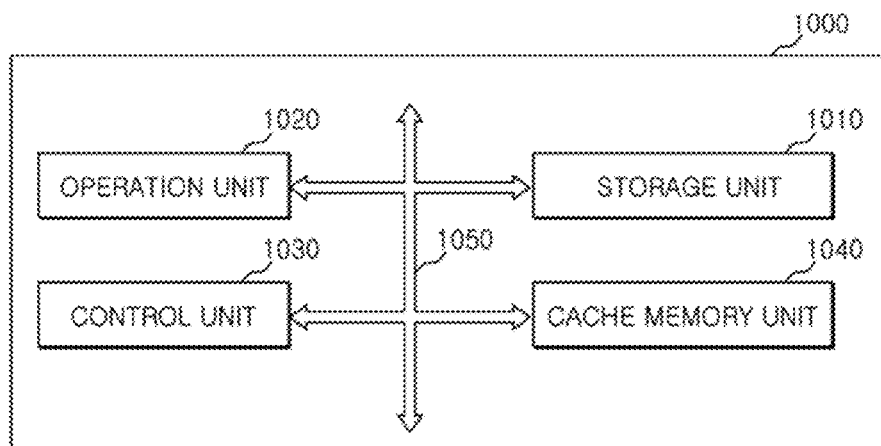


FIG. 12

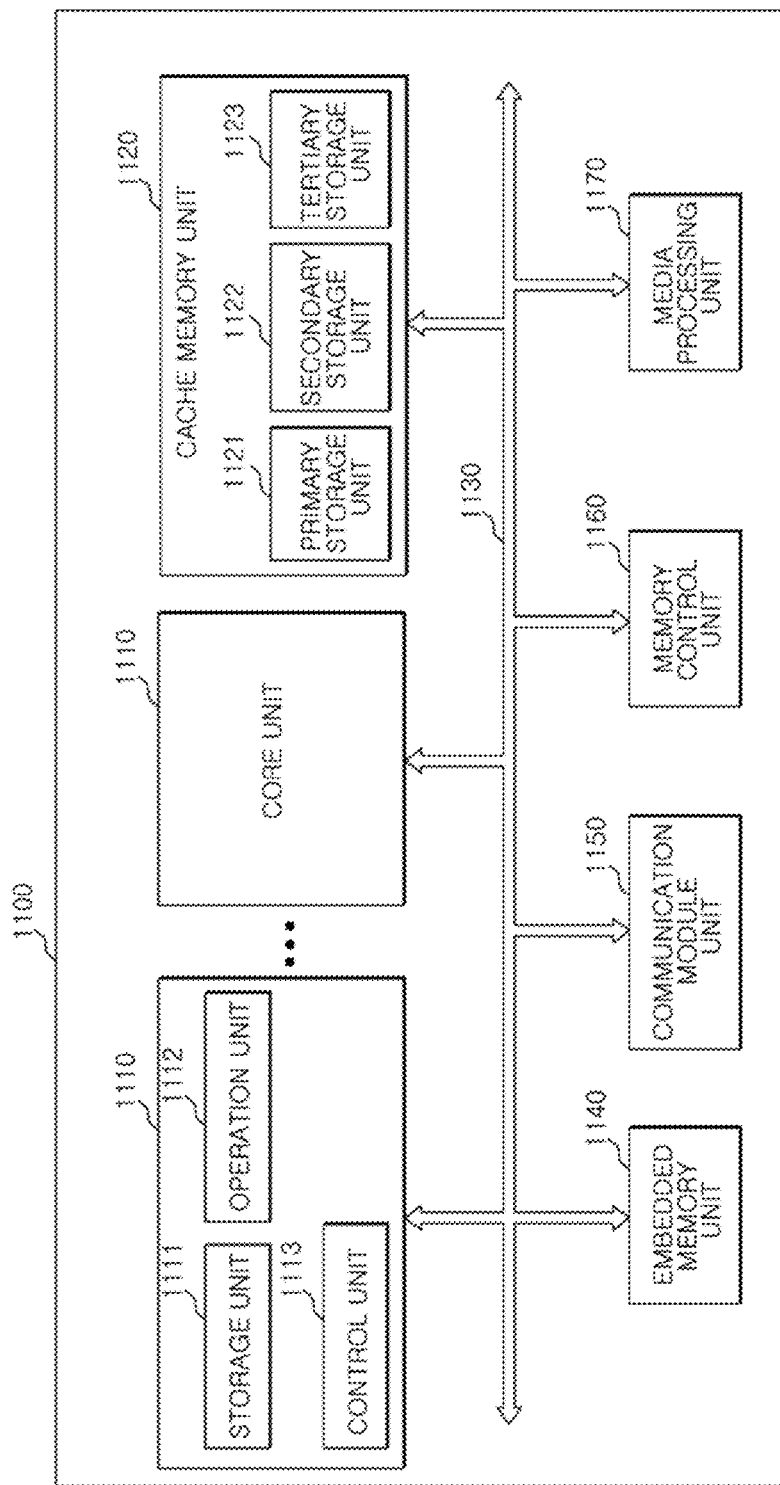
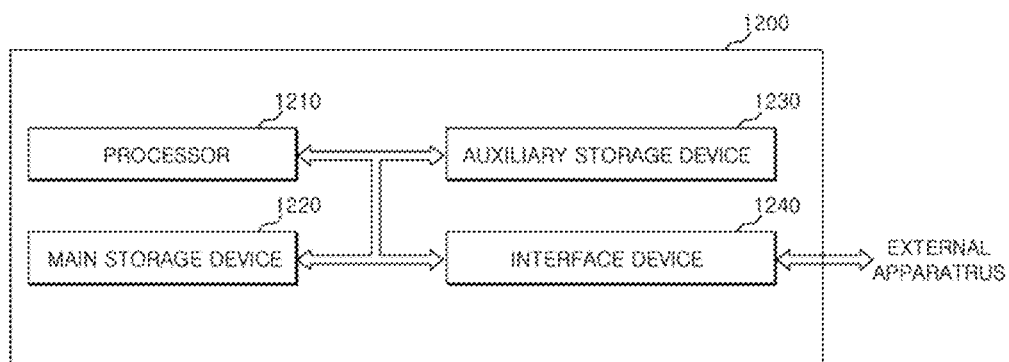


FIG. 13



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SEMICONDUCTOR DEVICE HAVING VERTICAL CHANNEL, RESISTIVE MEMORY DEVICE INCLUDING THE SAME, AND METHOD OF MANUFACTURING THE SAME

CROSS-REFERENCES TO RELATED APPLICATION

This application is a division of U.S. patent application Ser. No. 14/074,404 filed on Nov. 7, 2013, which claims priority under 35 U.S.C. 119(a) to Korean application No. 10-2013-0097806, filed on Aug. 19, 2013, in the Korean intellectual property Office. The disclosure of each of the foregoing application is incorporated by reference in its entirety as set forth in full.

BACKGROUND

1. Technical Field

Various embodiments of the inventive concept relate to a semiconductor integrated circuit device and a method of manufacturing the same, and, more particularly, to a semiconductor device having a vertical channel, a resistive memory device including the same, and a method of manufacturing the same.

2. Related Art

With the rapid development of mobile and digital information communication and the consumer-electronics industry, electronic charge controlled-devices may encounter limitations. Thus, new functional memory devices need to be developed. In particular, next-generation memory devices with large capacities, ultra-high speeds, and ultra-low powers need to be developed to satisfy demands of large capacity memories.

The use of resistive memory devices using a resistance device as a memory medium has been suggested as the next-generation of memory devices. Examples of resistance variable memory device may include phase-change random access memories (PCRAMs) resistive RAMs (ReRAMs), or magnetoresistive RAMs (MRAMs).

A resistive memory device may be formed of a switching device and a resistance device and may store data "0" or "1," according to a state of the resistance device.

Even in the variable resistive memory device, the first priority is to improve integration density and to integrate as many memory cells as possible in a limited and small area.

To satisfy these demands, the resistive memory device also employs a three-dimensional (3D) transistor structure. The 3D transistors may include a channel extending to a direction substantially perpendicular to a surface of a semiconductor substrate and a surrounded gate formed to surround the channel.

The 3D transistors may require a high operation current to maintain high resistance variable characteristics.

SUMMARY

An exemplary semiconductor device may include a pillar extending substantially perpendicular from a semiconductor substrate, the pillar including an inner portion and an outer portion surrounding the inner portion; a junction region formed in an upper region and a lower region of the vertical pillar; and a gate surrounding the pillar, wherein the inner portion of the pillar includes a semiconductor layer having a lattice constant that is larger than a lattice constant of the outer portion of the pillar.

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An exemplary resistive memory device may include a pillar including a channel region; a source formed in a source region located below the channel region; a drain formed in a drain region located on the channel region; a gate surrounding an outer circumference of the pillar; a heating electrode located over the drain; and a variable resistance layer located on the heating electrode, wherein the channel region of the pillar is subjected to a tensile stress based on a junction with the source region or the drain region.

An exemplary method of manufacturing a semiconductor device may include forming a first semiconductor layer on a semiconductor substrate, the first semiconductor layer having a lattice constant that is larger than a lattice constant of the semiconductor substrate; patterning the first semiconductor layer and the semiconductor substrate to form a preliminary pillar; forming a pillar by forming a second semiconductor layer having a same type of material as the semiconductor substrate on an outer circumference of the preliminary pillar; forming a gate insulating layer on the pillar and the semiconductor substrate; forming a drain in an upper portion of the pillar; forming, below the pillar, a source in the semiconductor substrate; and forming a gate surrounding an outer circumference of the pillar.

An exemplary microprocessor may include a control unit configured to receive an external signal from an external source and generate a control signal based on the external signal; an operation unit configured to perform an operation based on the control signal; and a storage unit configured to store data associated with the microprocessor or an address of data associated with the microprocessor, wherein the storage unit includes a transistor including a pillar having an inner portion and an outer portion surrounding the inner portion, wherein the inner portion and the outer portion have different lattice constants.

An exemplary processor may include a core unit configured to perform an operation based on a command input from an external source; a cache memory unit configured to store data associated with the processor or an address of data associated with the microprocessor; and a bus interface configured to interconnect the core unit and the cache memory unit, and to transmit data between the core unit and the cache memory device unit, wherein the cache memory unit includes a transistor including a pillar having an inner portion and an outer portion surrounding the inner portion, wherein the inner portion and the outer portion have different lattice constants.

An exemplary system may include a processor configured to receive an external signal from an external source and perform an operation based on the external signal; an auxiliary storage device configured to store data to be used by the processor; a main storage device configured to transfer the data the auxiliary storage device and store the data for use by the processor when the processor performs the operation; and an interface device configured to communicate between the external source and the processor, the auxiliary storage device, or the main storage device, wherein at least one of the auxiliary storage device and the main storage device includes a transistor including a pillar having an inner portion and an outer portion surrounding the inner portion, wherein the inner portion and the outer portion have different lattice constants.

These and other features, aspects, and exemplary implementations are described below in the section entitled "DETAILED DESCRIPTION".

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other aspects, features, and other advantages of the subject matter of the present disclosure will be

more clearly understood from the following detailed description taken in conjunction with the accompanying drawings, in which:

FIGS. 1 to 5 are cross-sectional views illustrating an exemplary method of manufacturing a semiconductor device having a vertical channel;

FIG. 6 is a cross-sectional view illustrating an exemplary resistive memory device including a semiconductor device having a vertical channel;

FIG. 7 is a perspective view illustrating an exemplary semiconductor device having a vertical channel;

FIGS. 8 to 10 are cross-sectional views illustrating an exemplary method of manufacturing the semiconductor device having a vertical channel;

FIG. 11 is a block diagram illustrating an exemplary microprocessor;

FIG. 12 is a block diagram illustrating an exemplary processor; and

FIG. 13 is a block diagram illustrating an exemplary system.

DETAILED DESCRIPTION

Hereinafter, exemplary implementations will be described in greater detail with reference to the accompanying drawings. Exemplary implementations are described herein with reference to cross-sectional illustrations that are schematic illustrations of exemplary implementations (and intermediate structures). As such, variations from the shapes of the illustrations as a result, for example, of manufacturing techniques and/or tolerances, are to be expected. Thus, exemplary implementations should not be construed as limited to the particular shapes of regions illustrated herein but may be to include deviations in shapes that result, for example, from manufacturing. In the drawings, lengths and sizes of layers and regions may be exaggerated for clarity. Throughout the disclosure, reference numerals correspond directly to the like numbered parts in the various figures and embodiments of the present invention. It should be readily understood that the meaning of “on” and “over” in the present disclosure should be interpreted in the broadest manner such that “on” means not only “directly on” but also “on” something with an intermediate feature(s) or a layer(s) therebetween, and that “over” means not only directly on top but also on top of something with an intermediate feature(s) or a layer(s) therebetween.

The inventive concept is described herein with reference to cross-section and/or plan illustrations that are schematic illustrations of exemplary implementations of the inventive concept. However, exemplary implementations of the inventive concept should not be construed as being limited to the illustrated exemplary implementations. It will be appreciated by those of ordinary skill in the art that changes may be made to the illustrated exemplary implementations without departing from the principles and spirit of the inventive concept.

Referring to FIG. 1, a semiconductor substrate 100 is prepared. The semiconductor substrate 100 may be, for example, a silicon (Si) substrate containing a first conductive impurity, such as a P-type impurity. A first semiconductor layer 110 and a second semiconductor layer 120 are sequentially deposited on the semiconductor substrate 100. The first semiconductor layer 110 may be formed of a material having a lattice constant larger than that of the semiconductor substrate 100. In an exemplary implementation, the first semiconductor layer 110 may include, for example, silicon germanium (SiGe), gallium arsenide (GaAs), indium arsenide (InAs), gallium antimonide (GaSb), indium antimonide (InSb), indium phosphide (InP), magnesium sulfide (MgS), magnesium selenide (MgSe), zinc

sulfide (ZnS), zinc selenide (ZnSe), zinc telluride (ZnTe), aluminum phosphide (AlP), gallium phosphide (GaP), aluminum arsenide (AlAs), aluminum antimonide (AlSb), cadmium sulfide (CdS), cadmium antimonide (CdSb), or cadmium telluride (CdTe). The first semiconductor layer 110 may be a region in which a substantial channel is to be formed in a subsequent process. A thickness of the first semiconductor layer 110 may be based on a length of the channel, and, for example, the first semiconductor layer 110 may be grown in a single crystalline structure through an epitaxial growth method. As the first semiconductor layer 110 is formed through an epitaxial growth method, carrier mobility characteristics may be improved as compared to a semiconductor layer having a polycrystalline structure.

The second semiconductor layer 120 may be formed on the first semiconductor layer 110. The second semiconductor layer 120 may be formed of the same material as the semiconductor substrate 100, for example, silicon (Si). The semiconductor layer 120 may be a region in which a drain region is to be formed in a subsequent process, and a length of the second semiconductor layer 120 may be based on a width of the drain region.

Referring to FIG. 2, the second semiconductor layer 120, the first semiconductor layer 110, and a portion of the semiconductor substrate 100 are patterned to form a preliminary pillar P1. The preliminary pillar P1 may have a line width smaller than an expected width of a vertical channel structure. The reference numeral 120a denotes a patterned second semiconductor layer, 110a denotes a patterned first semiconductor layer, and 100a denotes a patterned portion of the semiconductor substrate.

Referring to FIG. 3, a third semiconductor layer 125 having a lattice constant smaller than that of the first semiconductor layer 110 is formed on an outer wall of the preliminary pillar P1. For example, the third semiconductor layer 125 may be formed of the same material (such as silicon (Si)) as the semiconductor substrate 100 and the second semiconductor layer 120. The third semiconductor layer 125 may be formed using an epitaxial growth method. As the third semiconductor layer 125 is formed, the first patterned semiconductor layer 110a may be surrounded with a semiconductor material (for example, a silicon (Si) material) having a smaller lattice constant than that of the first patterned semiconductor layer 110a. Therefore an inner portion (corresponding to the first patterned semiconductor layer 110a) of the pillar P, which forms a substantial channel region, may be formed of a semiconductor material having a larger lattice constant than that of an outer portion (the semiconductor substrate, the second semiconductor layer, and the third semiconductor layer) of the pillar P.

Referring to FIG. 4, an oxidation process is performed on the pillar P and the exposed upper surface of the semiconductor substrate 100 to form a gate insulating layer 130. Although the gate insulating layer 130 in the exemplary implementation is formed through an oxidation process, this is not limited thereto, and the gate insulating layer 130 may be formed through a deposition method. If the gate insulating layer 130 is formed through a deposition method, then the gate insulating layer 130 may include a metal oxide, such as tantalum oxide (TaO), titanium oxide (TiO), barium titanate (BaTiO), barium zirconate (BaZrO), zirconium oxide (ZrO), hafnium oxide (HfO), lanthanum oxide (LaO), aluminum oxide (AlO), yttrium oxide (YO), zirconium silicide oxide (ZrSiO), nitride, or a combination thereof.

Referring to FIG. 5, a second conductive impurity, such as an N-type impurity may be implanted in a high concentration into an upper portion and a lower portion of the pillar P to

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form a drain D in the upper portion of the pillar P and form a source in the lower portion of the pillar P. The source may be formed in the entire semiconductor substrate (for example, a region corresponding to an active region) to operate as a common source CS. The drain D may be formed in a lightly doped drain (LDD) manner to reduce a short channel effect, such as gate-induced drain leakage (GIDL), and the drain D may be formed in the second patterned semiconductor layer **120a**. Next, a surrounded gate **140** may be formed on an outer circumference of the pillar P. The surrounded gate **140** may be formed to have a height lower than the pillar P. The surrounded gate **140** may include, for example, tungsten (W), copper (Cu), titanium nitride (TiN), tantalum nitride (TaN), tungsten nitride (WN), molybdenum nitride (MoN), niobium nitride (NbN), titanium silicon nitride (TiSiN), titanium aluminum nitride (TiAlN), titanium boron nitride (TiBN), zirconium silicon nitride (ZrSiN), tungsten silicon nitride (WSiN), tungsten boron nitride (WBN), zirconium aluminum nitride (ZrAlN), molybdenum silicon nitride (MoSiN), molybdenum aluminum nitride (WAlN), tantalum silicon nitride (TaSiN), tantalum aluminum nitride (TaAlN), titanium (Ti) molybdenum (Mo), tantalum (Ta), titanium silicide (TiSi), tantalum silicide (TaSi), titanium tungsten (TiW), titanium oxynitride (TiON), titanium aluminum oxynitride (TiAlON), tungsten oxynitride (WON), tantalum oxynitride (TaON), or doped polysilicon. The surrounded gate **140** may be formed, for example, using an anisotropic etching method. Next, an interlayer insulating layer **145** may be formed to be buried in the semiconductor substrate including the surrounded gate **140**.

As illustrated in FIG. 6, a heating electrode **150** and a variable resistance layer **155** are sequentially formed on the drain D to form a resistive memory device. The heating electrode **150** and the variable resistance layer **155** may be formed by sequentially forming a heating electrode layer and a variable resistance layer on the semiconductor substrate, including the interlayer insulating layer **145** and patterning a heating electrode layer (not shown) and a variable resistance layer (not shown) to remain in a location in which the heating electrode **150** is electrically coupled to the drain. If the heating electrode **150** includes a metal layer, then an ohmic contact layer (not shown) may be interposed [between what?].

As illustrated in FIG. 7, a vertical channel transistor may be formed so that a portion, in which a channel of the vertical channel P is formed, has a lattice constant that is larger than a lattice constant in regions in which junction regions (the source and drain) are formed. Therefore, tensile stress may be applied to the first patterned semiconductor layer **110a** due to differences of the lattice constants between the semiconductor substrate **100** and the first patterned semiconductor layer **110a** and between the first patterned semiconductor layer **110a** and the second patterned semiconductor layer **120a**. If the tensile stress is provided to the inner portion of the pillar P, that is, the first patterned semiconductor layer **110a**, then an electron mobility of an NMOS transistor may be considerably increased. Thus, a current drivability of the NMOS transistor may be improved. Further, the first patterned semiconductor layer **110a** is surrounded with the third semiconductor layer **130**, which has a lattice constant that is less than the lattice constant of the first patterned semiconductor layer **110a**, to further increase the tensile stress due to a lateral junction between the first patterned semiconductor layer **110a** and the third semiconductor layer.

In an alternative exemplary implementation, as illustrated in FIG. 8, a first patterned semiconductor layer **110a** of a preliminary pillar P1 may be configured of a stacking layer including a first sub-semiconductor layer **110-1**, a second

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sub-semiconductor layer **110-2**, and a third sub-semiconductor layer **110-3**. If the first patterned semiconductor layer **110a** is formed of SiGe, then the first sub-semiconductor layer **110-1** and the third sub-semiconductor layer **110-3** may be a SiGe layer (hereinafter, referred to as a low-Ge-concentration SiGe layer) having a concentration of Ge that is less than a concentration of Ge that forms a stoichiometric ratio of SiGe, and the second sub-semiconductor layer **110-2** may be a SiGe layer (hereinafter, referred to as a high-Ge-concentration-SiGe layer) having a concentration of Ge that is greater than a concentration of Ge that forms a stoichiometric ratio of SiGe. When content of Ge in the SiGe layer is increased, the lattice constant of the SiGe layer tends to increase. Therefore, a material having the largest lattice constant is formed in an effective channel zone of the first semiconductor layer **110a** to maximize electron mobility in the channel.

In an alternative implementation, illustrated in FIG. 9, a preliminary pillar P1 may include the patterned portion of the semiconductor substrate **100a** and a first patterned semiconductor layer **112**. In this alternative implementation, the second patterned semiconductor layer **120a** of FIG. 2 is not included. Therefore, the drain may be formed in an upper portion of the first patterned semiconductor layer **112**.

As illustrated in FIG. 10, a first patterned semiconductor layer **115** form a preliminary pillar P1 (as described in FIG. 9) without the second patterned semiconductor layer **120a** of FIG. 2. The first patterned semiconductor layer **115** may be configured of a Low-Ge-concentration-SiGe layer **115-1** and a high-Ge-concentration-SiGe layer **115-2**. The configuration of the first patterned semiconductor layer **115** may increase a lattice constant of a channel layer of a drain side to improve a drain current.

According to the exemplary implementations, the inner portion of the pillar having the inner portion and the outer portion, which a channel is substantially formed, may be configured of a material having a larger lattice constant than that of the outer portion. Therefore, a channel mobility of the NMOS transistor, that is, a current drivability of the NMOS transistor may be improved remarkably according to application of tensile stress to the inner portion of the pillar.

As illustrated in FIG. 11, an exemplary microprocessor **1000** may include an exemplary semiconductor device. The microprocessor **100** may control and adjust a series of processes, which receive and process data from an external source, and may communicate a processing result to the external source, and include a storage unit **1010**, an operation unit **1020**, or a control unit **1030**. The microprocessor **1000** may include a variety of processors, such as a central processing unit (CPU), a graphic processing unit (GPU) a digital signal processor (DSP), or an application processor (AP).

The storage unit **1010** may include a processor register or register and may store data in the microprocessor **1000**. The storage unit **1010** may include a data register, an address register, or a floating point register. The storage unit **1010** may include various registers other than the above-described registers. The storage unit **1010** may function to temporarily store data to be operated in the operation unit **1020**, resulting data processed in the operation unit **1020**, or an address in which data to be processed is stored.

The storage unit **1010** may include an exemplary semiconductor device. The storage unit **1010** including the exemplary semiconductor device may include a 3D semiconductor device in which an inner portion of a vertical channel has a larger lattice constant than an outer portion of the channel.

The operation unit **1020** may perform an operation inside the microprocessor **1000**, and may perform arithmetic or logic operations, depending on a decryption result of a com-

mand in a control unit **1030**. The operation unit **1020** may include one or more arithmetic and logic units (ALUs).

The control unit **1030** may receive a signal from the storage unit **1010**, the operation unit **1020**, or an external source, and may perform extraction or decryption of a command, or input or output control, or execute a process of a program form.

The exemplary microprocessor **1000** may further include a cache memory unit **1040** that may temporarily store data input from an external source or data to be output to an external source other than the storage unit **1010**. At this time, the cache memory unit **1040** may exchange data with the storage unit **1010**, the operation unit **1020**, or the control unit **1030** through a bus interface **1050**.

As illustrated in FIG. 12, an exemplary processor **1100** may include an exemplary semiconductor device. The exemplary processor **1100** may perform various functions to implement performance improvement and multifunction other than the microprocessor configured to control and adjust a series of processes, which receive and process data from various external apparatuses, and transmit a processing result to the external apparatuses. The processor **1100** may include a core unit **1110**, a cache memory unit **1120**, or a bus interface **1130**. The core unit **1110** may perform an arithmetic and a logic operation on data input from an external source. The core unit **1110** may include a storage unit **1111**, an operation unit **1112**, or a control unit **1113**. The processor **1100** may include a system on chips (SoCs) processor, such as a multi core processor (MCP), a GPU, or an AP.

The storage unit **1111** may include a processor register or a register. The storage unit **1111** may store data in the processor **1100** and may include a data register, an address register, or a floating point register. The storage unit **1111** may include various registers other than the above-described registers. The storage unit **1111** may temporarily store data to be operated in the operation unit **1112**, resulting data processed in the operation unit **1112**, or an address in which data to be processed is stored.

The operation unit **1112** may perform an operation inside the processor **1100**, and may perform arithmetic or logic operations depending on a decryption result of a command in the control unit **1113**. The operation unit **1112** may include one or more arithmetic and logic units (ALUs). The control unit **1113** may receive a signal from the storage unit **1111**, the operation unit **1112**, or an external device of the processor **1100**, perform extraction or decryption of a command, or input or output control, and execute a process of a program form.

The cache memory unit **1120** may temporarily store data to supplement a data processing rate of a low speed external apparatus, unlike the high speed core unit **1110**, and may include a primary storage unit **1121**, a secondary storage unit **1122**, or a tertiary storage unit **1123**. In general, the cache memory unit **1120** may include the primary and secondary storage units **1121** and **1122**, and if a high capacity storage unit is necessary, then the cache memory unit **1120** may include the tertiary storage unit **1123**. If necessary, the cache memory **1120** may include more storage units. That is, the number of storage units included in the cache memory unit **1120** may be changed according to a design rule. Here, processing rates of data storage and discrimination of the primary, secondary, and tertiary storage units **1121**, **1122**, and **1123** may be the same as or different from each other. If the processing rates of the storage units are different, then the processing rate of the primary storage unit may be the highest. One or more of the primary storage unit **1121**, the secondary storage unit **1122**, and the tertiary storage unit **1123** in the cache memory unit may include an exemplary semiconductor

device. The cache memory unit **1120** including the exemplary semiconductor device may include a 3D semiconductor device in which an inner portion of a vertical channel has a larger lattice constant than an outer portion of the vertical channel.

FIG. 12 illustrates that the primary, secondary, tertiary storage units **1121**, **1122**, and **1123** are located inside of the cache memory unit **1120**. However, the primary, secondary, tertiary storage units **1121**, **1122**, and **1123** in the cache memory unit **1120** may be located outside of the core unit **1110**, and may supplement a difference in processing rates between the core unit **1110** and an external device. Further, the primary storage unit **1121** of the cache memory unit **1120** may be located inside of the core unit **1110**, and the secondary storage unit **1122** and the tertiary storage unit **1123** may be located outside of the core unit **1110** to enforce a function to compensate a processing rate.

The bus interface **1130** may couple the core unit **1110** and the cache memory unit **1120** to efficiently transmit data.

The processor **1100** according to the exemplary implementation may include a plurality of core units **1110**, and the plurality of core units **1110** may share the cache memory unit **1120**. The plurality of core unit **1110** and the cache memory unit **1120** may be, coupled through the bus interface **1130**. The plurality of core units **1110** may have same configuration as the configuration of the above-described core unit **1110**. When the plurality of core unit **1110** are provided, the primary storage units **1121** of the cache memory unit **1120** corresponding to the number of core units **1110** may be configured in the core units **1110**, and the secondary storage unit **1122** and the tertiary storage unit **1123** may be configured in one body in the outsides of the core units **1110** to be shared through the bus interface **1130**. Here, the processing rate of the primary storage unit **1121** may be larger than those of the secondary and tertiary storage units **1122** and **1123**.

The exemplary processor **1100** may further include an embedded memory unit **1140** that may store data, a communication module unit **1150** that may transmit and receive data to and from an external device in a wired or wireless manner, a memory control unit **1160** that may drive an external storage device, or a media processing unit **1170** that may process data processed in the processor **1100** or data input from an external device and output a processing result to an external interface device. The exemplary processor **1100** may further include a plurality of modules. At this time, a plurality of added modules may transmit or receive to or from the core unit **1110**, the cache memory unit **1120**, or between the modules through the bus interface **1130**.

The embedded memory unit **140** may include a volatile memory or a nonvolatile memory. The volatile memory may include a dynamic random access memory (DRAM), a mobile DRAM, a static random access memory (SRAM), or the like, and the nonvolatile memory may include a read only memory (ROM) a NOR flash memory, a NAND flash memory, a phase-change random access memory (PRAM), a resistive RAM (ReRAM), a spin transfer torque RAM (STTRAM), a magnetic RAM (MRAM), or the like. The exemplary semiconductor device may be applied to the embedded memory **1140**.

The communication module unit **1150** may include a module configured to be coupled to a wired network and a module configured to be coupled to a wireless network module. The wired network module may include a local area network (LAN), a universal serial bus (USB), Ethernet, a power line communication (PLC), or the like, and the wireless network module may include Infrared Data Association (IrDA), Code Division Multiple Access (CDMA), Time Division Multiple

Access (TDMA), Frequency Division Multiple Access (TDMA), a wireless LAN, Zigbee, a Ubiquitous Sensor Network (USN), Bluetooth, Radio Frequency Identification (RFID), Long Term Evolution (LTE), Near Field Communication (NFC), Wireless Broadband Internet (Wibro), High Speed Downlink Packet Access (HSDPA), Wideband CDMA (WCDMA), Ultra WideBand (UWB), or the like.

The memory control unit **1160** may manage data transmitted between the processor **1100** and an external device configured to operate according to a different communication standard from the processor **1100**, and may include a variety of memory controllers, such as a memory controller that may control an Integrated Device Electronics (IDE), a Serial Advanced Technology Attachment (SATA), a Small Computer System Interface (SP_CSI), a Redundant Array of Independent Disks (RAID), a solid state disk (SSD), External SATA (eSATA), a Personal Computer Memory Card International Association (PCMCIA), a USB a secure digital (SD) card, a mini secure digital (mSD) card, a micro SD card, a secure digital high capacity (SDHC) card, a memory stick card, a smart media card (SM), a multi-media card (MMC), an embedded MMC (eMMC), a compact flash (CF) card, or the like.

The media processing unit **1170** may process data processed in the processor **1100** or data input from an external input device and output a processing result to an external interface device to be transferred in video, audio, or another format. The media processing unit **1170** may include a GPU, a DSP, a HD audio, a high definition multimedia interface (HDMI) controller, or the like.

As illustrated in FIG. 13, an exemplary system **1200** may include an exemplary semiconductor device. The exemplary system **1200** may perform an input operation, a processing operation, an output operation, a communication operation, a storage operation, or the like on data. The exemplary system **1200** may include a processor **1210**, a main storage device **1220**, an auxiliary storage device **1230**, or an interface device **1240**. The exemplary system **1200** may be a variety of electronic systems configured to operate using a processor, such as a computer, a server, a personal digital assistant (PDA), a portable computer, a web tablet, a wireless phone, a mobile phone, a smart phone, a digital music player, a portable multimedia player (PMP), a camera, a global positioning system (GPS), a video camera, a voice recorder, Telematics, an audio visual (AV) system, or a smart television.

The processor **1210** may control an interpretation of an input command and processing, such as an operation, comparison, or the like of data stored in the exemplary system **1200**. The processor **1210** may be a MPU, a CPU, a single/multi core processor, a GPU, an AP, a DSP, or the like.

The main storage unit **1220** may transfer and execute a program or data from the auxiliary storage device **1230** when a program is executed. The main storage device **1220** retains the stored content in power off, and may include the exemplary semiconductor device. The main storage device **1220** may include a 3D semiconductor device in which an inner portion of a vertical channel has a lattice constant larger than that of an outer portion of the vertical channel.

An exemplary main storage device **1220** may further include an SRAM or a DRAM of a volatile memory type in which all contents are erased in power off. Alternatively, the main storage device **1220** may not include the exemplary semiconductor device, but may include an SRAM or a DRAM of a volatile memory type in which all contents are erased in power off.

The auxiliary storage device **1230** may store a program code or a data. The auxiliary storage device **1230** may have a

lower data processing rate than the main storage device **1220**, but may store a large amount of data and may include the exemplary semiconductor device. The auxiliary storage unit **1230** may also include a 3D semiconductor device in which an inner portion of a vertical channel has a lattice constant larger than that of an outer portion of the vertical channel.

An exemplary auxiliary storage device **1230** may reduce an area to reduce a size of the system **1200** and increase portability. Further, the auxiliary storage device **1230** may further include a data storage system (not shown) such as a magnetic tape or a magnetic disc using a magnetism, a laser disc using light, a magneto-optical disc using a magnetism and light, an SSD, a USB memory, a SD card, a mSD card, a micro SD card, a SDHC card, a memory stick card, a smart media card, a MMC card, an eMMC, or a CF card. Alternatively, the auxiliary storage device **1230** may not include the exemplary semiconductor device, but include a data storage system (not shown), such as a magnetic tape or a magnetic disc using a magnetism, a laser disc using light, a magneto-optical disc using a magnetism and light, an SSD, a USB memory, a SD card, a mSD card, a micro SD card, a SDHC card, a memory stick card, a smart media card, a MMC card, an eMMC, or a CF card.

The interface device **1240** may exchange a command and data of an external apparatus with the system of the exemplary implementation, and may be a keypad, a keyboard, a mouse, a speaker, a mike, a display, a variety of Human. Interface Devices (HIDs), or a communication device. The communication device may include all modules such as a module configured to be coupled to a wired network and a module configured to be coupled to a wireless network. The wired network module may include a LAN, a USB, Ethernet, a PLC, and the like, and the wireless network module may include IrDA, CDMA, TDMA, FNMA, a wireless LAN, Zigbee, a USN, Bluetooth, RFID, LTE, NFC, Wibro, HSDPA, WCDMA, UWB, or the like.

The above exemplary implementation of the present invention is illustrative and not limitative. Various alternatives and equivalents are possible. The invention is not limited by the exemplary implementation described herein. Nor is the invention limited to any specific type of semiconductor device. Other additions, subtractions, or modifications are obvious in view of the present disclosure and are intended to fall within the scope of the appended claims.

What is claimed is:

1. A method of manufacturing a semiconductor device, the method comprising:

- forming a first semiconductor layer on a semiconductor substrate, the first semiconductor layer having a lattice constant that is larger than a lattice constant of the semiconductor substrate;
- forming a second semiconductor layer on the first semiconductor layer;
- patterning the second semiconductor layer, the first semiconductor layer, and the semiconductor substrate to form a preliminary pillar;
- forming a third semiconductor layer surrounding an outer circumference of the preliminary pillar to define a pillar;
- forming a gate insulating layer on the pillar and the semiconductor substrate;
- forming a drain in the second semiconductor layer;
- forming, below the pillar, a source in the semiconductor substrate; and
- forming a gate surrounding an outer circumference of the pillar,

wherein each of the second semiconductor layer and the third semiconductor layer has a lattice constant that is smaller than a lattice constant of the first semiconductor layer.

2. The method of claim 1, wherein at least one of the semiconductor substrate, the second semiconductor layer, and the third semiconductor layer includes a silicon (Si) material.

3. The method of claim 1, wherein at least one of the semiconductor substrate, the first semiconductor layer, the second semiconductor layer, and the third semiconductor layer formed on the outer circumference of the preliminary pillar is formed through an epitaxial growth method.

4. The method of claim 1, wherein the forming the first semiconductor layer includes:

forming a first low-Ge-concentration-SiGe layer, having a concentration of Ge that is less than a concentration of Ge that forms a stoichiometric ratio of SiGe, on the semiconductor substrate; and

forming a high-Ge-concentration-SiGe layer, having a concentration of Ge that is greater than the concentration of Ge that forms the stoichiometric ratio of SiGe, on the first Ge-low concentration-SiGe layer.

5. The method of claim 4, wherein the forming the first semiconductor layer further comprises:

forming a second low-Ge-concentration-SiGe layer on the high-Ge-concentration-SiGe layer.

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